International Civil Aviation Organization
North American, Central American and Caribbean Office

WORKING PAPER

GTE/22 — WP/13
26/09/22

CAR/SAM Planning and Implementation Regional Group (GREPECAS) Twenty Second Scrutiny Working Group Meeting (GTE/22)

Mexico City, Mexico, 26 to 30 September 2022

Agenda Item 3: Review of the Results of Large Height Deviation (LHD) Analysis

VERTICAL SAFETY MONITORING REPORT FOR MIAMI OCEANIC, NEW YORK WEST, AND SAN JUAN AIRSPACE – 2021

(Presented by NAARMO)

EXECUTIVE SUMMARY

This paper provides the vertical safety monitoring report for the continued safe use of the Reduced Vertical Separation Minimum (RVSM) in Miami Oceanic, New York West, and San Juan Airspace. The safety assessment has been conducted according to the methodology endorsed by the International Civil Aviation Organization (ICAO). This work makes use of Large Height Deviation (LHD) reports and Traffic Sample Data (TSD) for calendar year 2021.

The purpose of this report is to compare actual performance to safety goals related to continued use of the RVSM in Miami Oceanic, New York West, and San Juan Airspace. This report contains a summary of LHD reports received by the NAARMO for the calendar year 2020. There are 29 reported events accounting for 62 minutes spent at an unexpected/incorrect Flight Level (FL) during calendar year 2021. This report also contains an estimate of the vertical collision risk. The vertical collision risk estimate for the airspace exceeds the Target Level of Safety (TLS) value of 5.0 × 10-9 fatal accidents per flight hour.

Action:	Note and discuss information provided
Strategic Objectives:	• Strategic Objective 1 – Safety • Strategic Objective 2 – Air Navigation Capacity and Efficiency
References:	• ICAO Doc 9574 • ICAO Doc 9937

1. Introduction

1.1 The North American Approvals Registry and Monitoring Organization (NAARMO), a service delegated to the WJH Technical Center, fulfills the role of Regional Monitoring Agency (RMA) for the continued-safe use of the RVSM in the Miami Oceanic, New York West, and San Juan airspace.

1.2 This airspace primarily contains operations travelling between North America and the Caribbean. The U.S. FAA is the Air Traffic Service (ATS) provider for the Miami Oceanic, New York and San Juan Flight Information Regions (FIRs). Figure 1-1 shows the location of the airspace. The RVSM was introduced in November 2001 into this airspace. The NAARMO conducts the on-going airspace safety monitoring activities to help ensure the continued safe use of the RVSM.

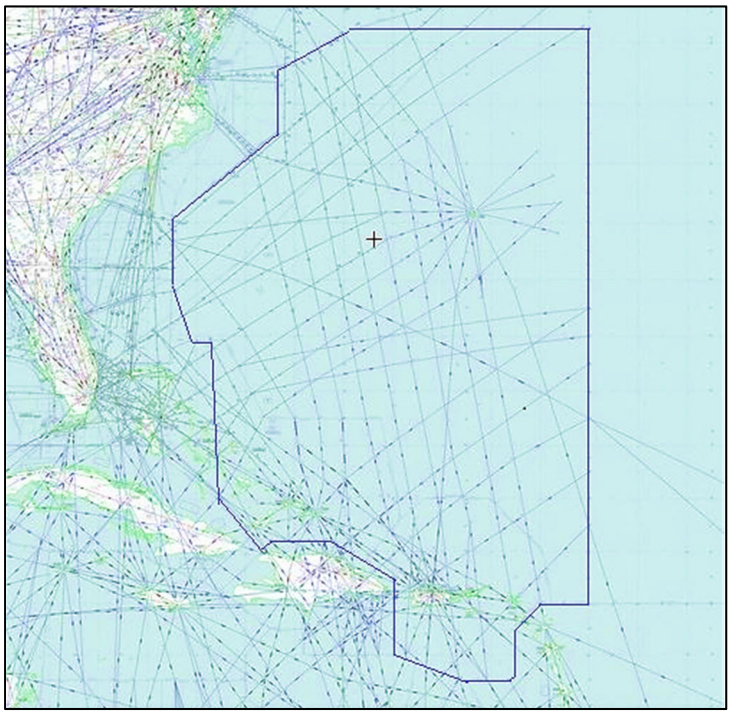


Figure 1-1. Miami Oceanic, New York West, San Juan FIRs

1.3 This report covers the calendar year 2021. Within this report, the reader will find a summary of the Large Height Deviation (LHD) reports received by the NAARMO and the corresponding vertical collision risk estimate. There were 48 such reports submitted to the NAARMO for calendar year 2021.

2. Discussion

2.1 *Traffic Sample Data*

2.1.1 The NAARMO has access to the Federal Aviation Administration's (FAA's) Traffic Flow Management System (TFMS), which includes aircraft observations in Miami Oceanic and San Juan airspace. Each traffic movement record within the TFMS data sample contains the date, time, latitude, longitude, flight level (FL), aircraft flight identification, aircraft type, origin airport and the destination airport. The TFMS data contain frequent position estimates for each flight – a position estimate is provided approximately once a minute.

2.1.2 The source of traffic data for the New York West FIR is the FAA Advanced Technologies and Oceanic Procedures (ATOP) oceanic automation system data reduction and archives (DR&A). These data contain all the reported aircraft positions, as well as the pilot-ATC High Frequency (HF) radio communications and Controller Pilot Data Link Communications (CPDLC) messages. Figure 2-1 shows the aircraft position locations within the New York West FIR and the TFMS data for the Miami Oceanic and San Juan FIRs for 11 December 2021. The Miami Oceanic and San Juan traffic observed in the TFMS data are combined with the New York West traffic observed in the ATOP DR&A.

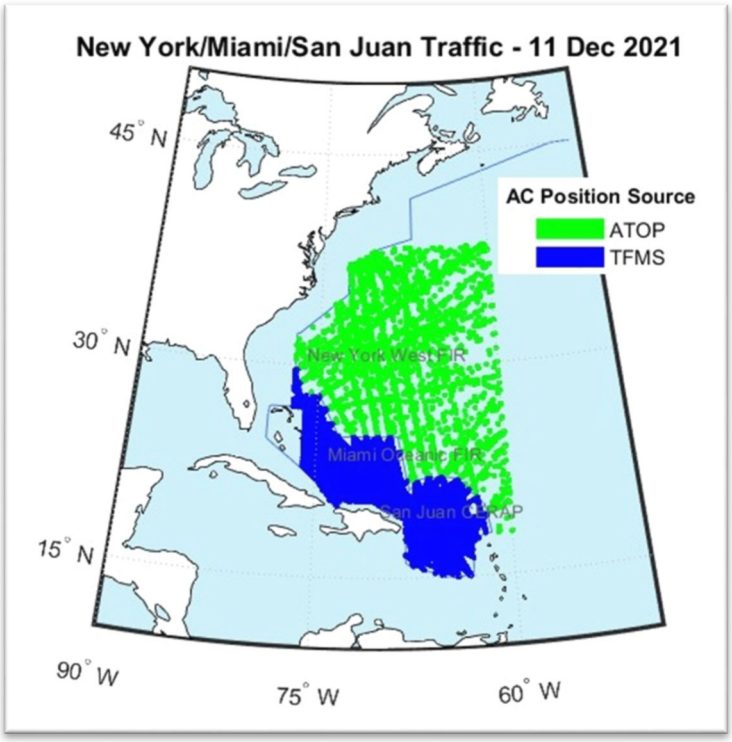


Figure 2-1. Miami Oceanic, New York West, San Juan FIRs Air Traffic Operations – 11 Dec 2021

2.1.3 **Figure 2-2** shows the number of flight operations per month for the New York West FIR for calendar year 2020 through July 2022. The vertical axis represents the total number of flight operations observed each month. The reduction in air travel from the COVID-19 pandemic and the recovery is visible in the figure. In January 2020, the average number of flight operations per day was 708 in the New York West FIR. In January 2021, the average number of flight operations per day was 393. In December 2021, the average number of flight operations per day was 676.

2.1.4 In normal times, seasonal variations in traffic volume are expected. Typically, the high traffic period for Miami Oceanic, New York West, and San Juan airspace begins in November and ends in April/May. Figure 2-2 shows that by the end of calendar year 2021, traffic levels are increasing and a sustained recovery in the number of operations is observed in the current data plotted through July 2022.

2.1.5 **Figure 2-3** shows the numbers of flight operations per day for calendar year 2021. The average number of flights per day for calendar year 2021 was 448 flights. Figure 2-3 shows the seasonal variation combined with the pandemic related recovery in flight activity.

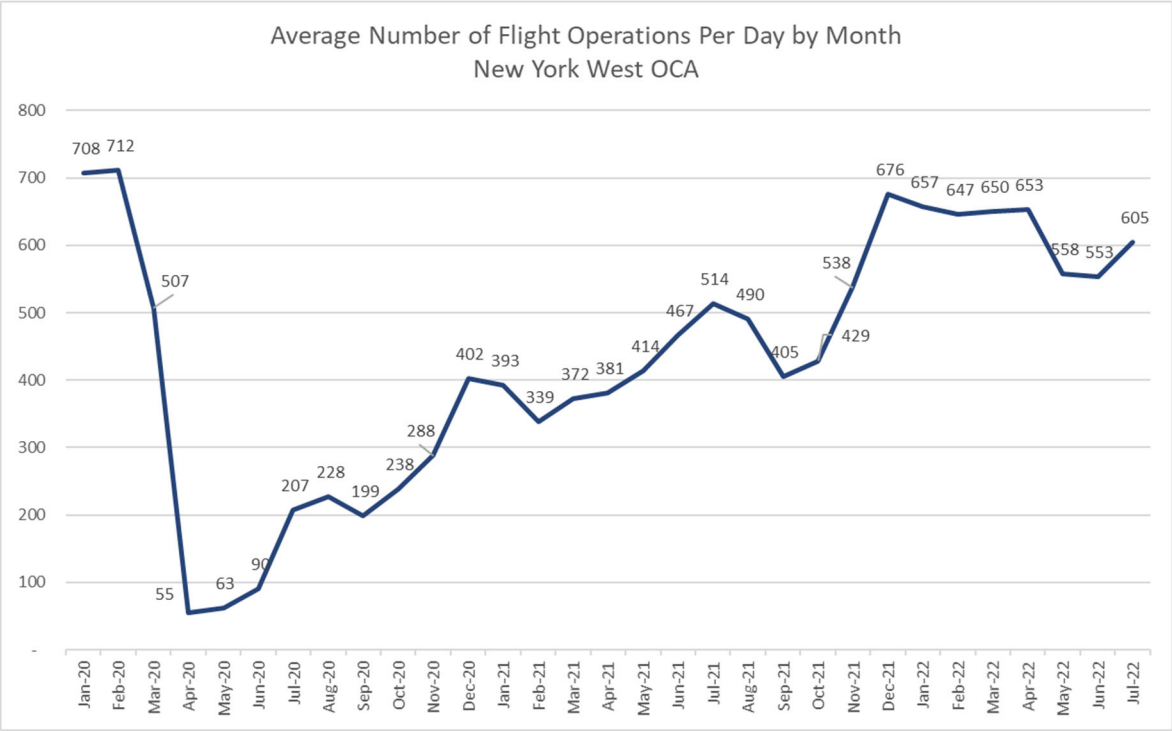


Figure 2-2. New York West FIR, average number of flight operations per day by month – calendar year 2020 through July 2022

2.2 *Reported Large Height Deviations (LHDs)*

2.2.1 The NAARMO utilizes the FAA's Comprehensive Electronic Data Analysis and Reporting (CEDAR) database, which contains all reports of potentially safety-related events from several internal FAA sources. There were 48 reported occurrences reviewed by the scrutiny group for the Miami Oceanic, New York West, and San Juan airspace. The scrutiny group consists of operational experts from each air traffic control facility, representatives from FAA Flight Standards and Airspace Safety, and safety analyses experts from the NAARMO. The scrutiny group met virtually several times and reviewed all forty-eight reported occurrences from calendar year 2021. Resulting from the work of the scrutiny group, there were twenty-nine validated LHD occurrences during calendar year 2021. Table 2-1 contains a summary of all the validated LHDs by month.

2.2.2 The 29 validated LHD reports are tabulated by month and shown in Table 2-1. Table 2-1 includes the number of reports, LHD duration and the flight levels crossed without clearance by month. The scrutiny group review determined a general cause for each of the 29 validated LHD reports. Table 2-2 summarizes the reported LHDs categorized by general cause. Nine of the twenty-nine reported LHDs listed in Table 2-2 are classified as technical risk events. The technical risk LHDs include three category I and six category L events. The associated duration and/or flight levels crossed for the technical risk LHDs are not included in calculation of operational vertical risk and are not shown in Table 2-2. Only the reported LHDs classified as operational risk and their associated duration at incorrect FL and number of incorrect FLs crossed without ATC clearance contribute to the operational vertical collision risk estimate.

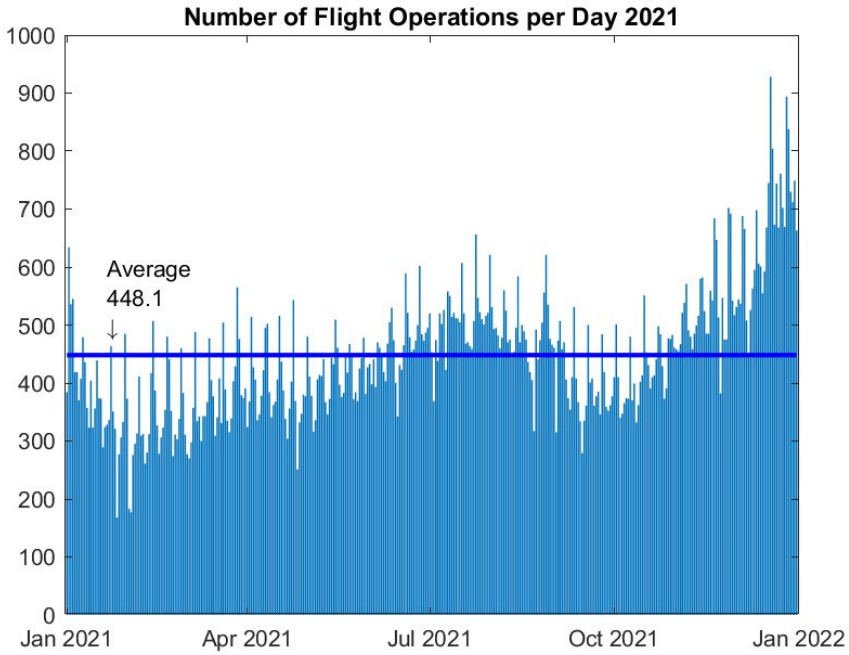


Figure 2-3. New York West FIR, Number of flight operations per day – calendar year 2021

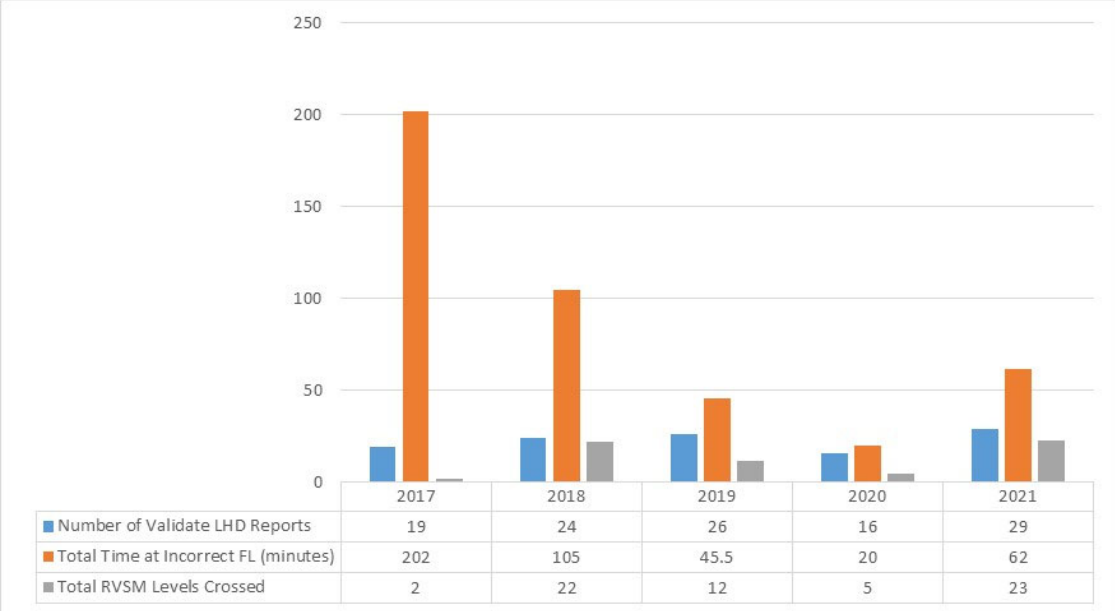
Table 2-1. Validated LHDs – 2021

Month	Count	Duration at Unexpected FL (mins)	Number of Unexpected FLs Crossed
Jan-21	1	0	0
Feb-21	2	4	8
Mar-21	1	0	1
Apr-21	4	1	2
May-21	2	0	2
Jun-21	3	1	0
Jul-21	2	1	0
Aug-21	3	2	0
Sep-21	0	0	0
Oct-21	1	0	9
Nov-21	4	11	0
Dec-21	5	42	1
TOTAL	**29**	**62**	**23**

Table 2-2**. Validated LHD Reports by Cause – 2021**

LHD Category Code	LHD Category Description	Number of LHD	Duration at Incorrect FL (minutes)	Number of Incorrect FLs Crossed
A	Flight crew failing to climb / descend the aircraft as cleared	1	0	0
B	Flight crew climbing /descending without ATC clearance	3	0	9
C	Incorrect operation of airborne equipment	1	9	1
D	ATC system loop error; (e.g., ATC issues incorrect clearance or flight crew misunderstands clearance message)	2	30	0
E	Coordination errors in the ATC-unit-to-ATC-unit transfer of control responsibility as a result of human factors issues	11	23	3
F	Coordination errors in the ATC-to-ATC transfer of control responsibility as a result of equipment outage or technical issues	0	0	0
G	Aircraft contingency event leading to sudden inability to maintain assigned flight level	2	0	10
H	Airborne equipment failure leading to unintentional or undetected change of flight level	0	0	0
I	Turbulence or other weather related causes – *contributes towards technical risk*	3	0	0
J	TCAS resolution advisory; flight crew correctly following the resolution advisory	0	0	0
K	TCAS resolution advisory; flight crew incorrectly following the resolution advisory	0	0	0
L	An aircraft being provided with RVSM separation is not RVSM approved (e.g. flight plan indicating RVSM approval but aircraft not approved, ATC misinterpretation of flight plan) – *contributes towards technical risk*	6	0	0
M	Other	0	0	0
	TOTAL	**29**	**62**	**23**

2.2.3 An increase in both the number of reported LHDs and duration spent at the unexpected/incorrect FL was observed in 2021 compared to the previous years. This result was expected due to the ongoing recovery from the COVID-19 pandemic and associated increase in flight activity. **Figure 2-4** shows the comparison in the numbers of validated LHDs, duration and flight levels crossed without ATC Clearance for calendar years 2017 through 2021. The numbers of reported LHDs in 2021 is comparable to the number of reported LHDs during pre-COVID years, however, the associated LHD durations have decreased. One reason for this decrease in durations is the increased use of advanced technology in oceanic and remote airspace. Data link operations in New York West airspace provide ATC with more frequent alerts for climbs/descends that are not in accordance with an ATC clearance. The available surveillance in the Miami Oceanic and San Juan areas provide alerts to ATC for unexpected climbs/descends.



	2017	2018	2019	2020	2021
Number of Validate LHD Reports	19	24	26	16	29
Total Time at Incorrect FL (minutes)	202	105	45.5	20	62
Total RVSM Levels Crossed	2	22	12	5	23

Figure 2-4. Validated LHD Reports, calendar years 2017 through 2021

2.2.4 There was an increase in the number of reported LHDs involving the transfer of ATC control. There were eleven category E events in 2021. In 2020, there were six reported occurrences with a total of nine minutes duration that involved the transfer of ATC control. During the scrutiny reviews, ATC operational experts indicated these category E occurrences are discussed during routine teleconferences attended by representatives from the adjacent facilities. For example, the Miami, Houston, and Havana ATC centers have a weekly automatic data exchange (ADE) teleconference that provides opportunities to discuss related issues.

2.2.5 There was one reported category A LHD that was caused by misunderstanding of CPDLC conditional clearances.

2.2.6 There were three reported category B LHDs. Two of these reported LHDs involved an aircraft contingency event with a secondary category G was marked. One of these reported occurrences involved the incorrect application of the in-flight contingency procedure for weather.

2.2.7 There were two reported category G LHDs. Both of these reported LHDs involved a pressurization issue with the aircraft.

2.2.8 There was one long-duration category D LHD that occurred within New York West OCA. A long-duration LHD has a duration of 20 minutes or more. The estimated duration at an unprotected flight level for this occurrence was 29 minutes, there was an ATC loss of separation. As a result of this occurrence, there is a software fix for the automation system. This software fix will help alert ATC to assist in identifying a potential incorrect route amendment. The center has also conducted ATC refresher training related to the causes of this occurrence.

2.2.9 The operational risk-bearing LHD events are separated into two areas; those occurring within New York West airspace and those occurring within the Miami Oceanic/San Juan Flight Information Regions (FIRs) and New York West boundary. **Table 2-3** contains the breakdown of operational LHD events and associated durations for each area. It is noted that Table 2-3 does not contain the nine validated LHDs associated with technical risk. Figure 2-5 shows the approximate locations of the operational LHDs in 2021. The locations of the category E events occur on an ATC boundary.

Table 2-3. Validated operational LHDs by area – 2021

Airspace	Number of LHD	Duration at unexpected FL (min)	Number of unexpected FLs crossed
Miami Oceanic/San Juan FIRs and New York West boundary	9	9	3
New York West FIR	11	53	20
Total	**20**	**62**	**23**

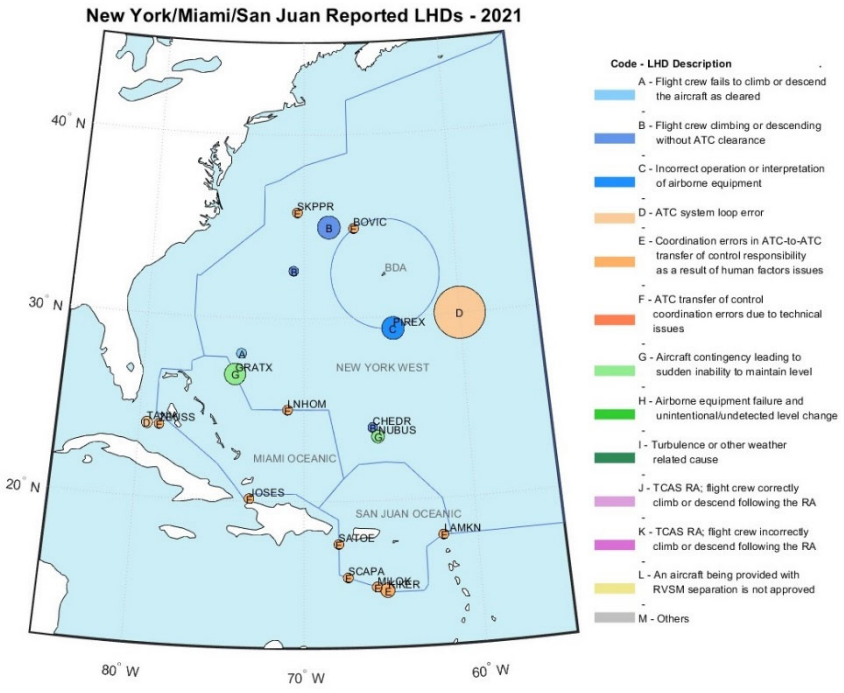


Figure 2-5. Approximate Location of the Risk-bearing LHDs – 2021

2.2.10 Vertical Collision Risk Estimate

2.2.11 This section of the paper provides the parameter estimates used in the ICAO vertical risk model. The collision risk methodology consists of a mathematical model to estimate risk for comparison to the safety criterion, the target level of safety (TLS). The section also provides information on the sources of data used to estimate risk model parameters.

2.2.12 The internationally agreed TLS for the 1,000-ft vertical separation standard is specified for technical and operational risk separately. The vertical technical risk provides the risk associated the with effects of turbulence, loss of altitude hold and crew response to airborne collision-avoidance system alerts in addition to errors arising from aircraft altimetry and altitude height-keeping system performance. The vertical operational risk estimate provides the risk associated with operational errors. The risk due to all causes is the sum of the vertical operational and technical risk estimates. The TLS for the 1,000-ft vertical separation standard is specified as

- collision risk due to all causes does not exceed 5 fatal accidents in 10^9 flying hours, and, simultaneously,
- collision risk due to aircraft height-keeping systems does not exceed 2.5 fatal accidents in 10^9 flying hours

2.2.13 Based on the December 2021 traffic data, the NAARMO estimates approximately 618,437 annual flying hours for 2021 in Miami Oceanic, New York West, and San Juan airspace where the RVSM is applied. This represents an average **54 percent increase in flying hours compared to 2020**.

2.2.14 The methodology applied in the collision risk calculation for the airspace splits the airspace into two areas. The New York West airspace is considered separately from Miami Oceanic and San Juan airspace. Although the aircraft operations are similar within both areas, the available ATC surveillance and communications differ. In addition, there are differences in the available traffic data source for the two areas. The individual risk estimates for each area are combined to provide an estimate of the airspace using the observed annual flying hours within each area.

2.2.15 The airspace consists of a combination of parallel and crossing routes; therefore the total risk is expressed as the sum of three basic types of collision risk as follows:

$$N_{az}=N_{az}(same)+N_{az}(opp)+N_{az}(cross)$$

2.2.16 The terms on the right hand side of the equation represent the expected number of accidents per aircraft flight hour resulting from collisions of aircraft-pairs assigned to adjacent flight levels due to the loss of planned vertical separation. The three terms on the right hand side are estimated from aircraft operating on adjacent flight levels that are flying in the same direction on the same route, Naz(same), opposite direction on the same route, Naz(opp), and on crossing routes regardless of relative headings, Naz (cross).

2.2.17 The models for the three different types of collision risk - opposite-direction, same-direction, and crossing-routes - have basically the same structure. The estimate of vertical operational risk for same and opposite direction traffic is composed of two parts: that due to time spent at incorrect levels and that due to levels transitioned without clearance.

2.2.18 Aircraft Types Observed in Miami Oceanic, New York West, and San Juan FIRs

2.2.19 **Figure 2-6** provides the top aircraft types observed in the December 2021 traffic data by flying hours. The two traffic data sources are maintained in the figure; Miami Oceanic and San Juan traffic data are sourced from the TFMS and the New York West data are sourced from the ATOP DR&A. The aircraft types in **Figure 2-6** account for more than 70 percent of total flying hours observed in the airspace. The Airbus A321 is the most frequently observed aircraft in the New York West airspace. The Boeing B738 is the most frequently observed aircraft in the Miami Oceanic and San Juan airspace.

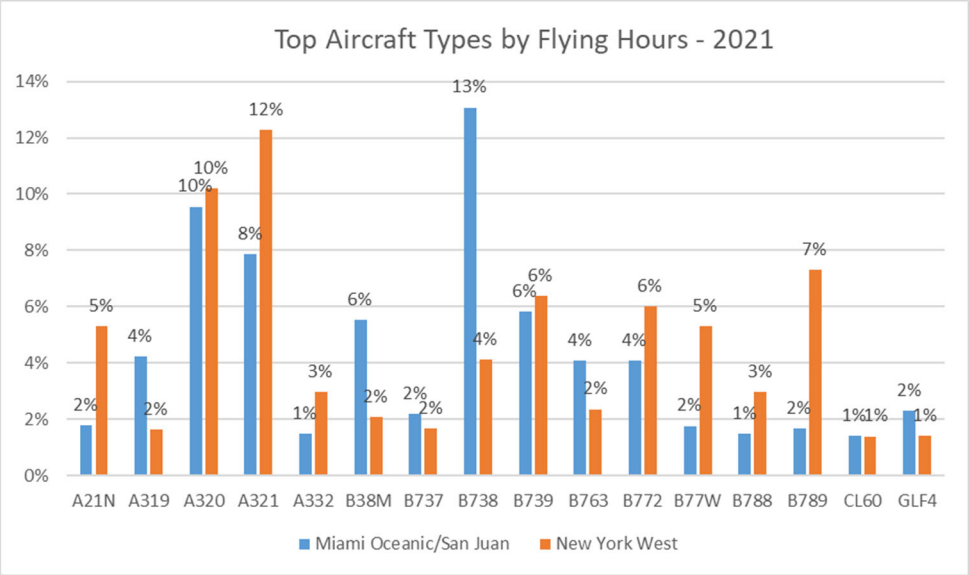


Figure 2-6. Observed Aircraft Types in Terms of Flying Hours in Miami Oceanic/San Juan and New York West Airspace - 2021

2.2.21 The collision risk model (CRM) parameters related to the aircraft size are: length, wingspan, and height. These parameters are estimated directly from the TFMS and ATOP DR&A December 2021 data and related aircraft specifications. The weighted dimensions are calculated using the actual dimensions of the aircraft type multiplied by the proportion of total flying time observed for the type in the traffic sample. The resulting CRM parameters for the aircraft length, wingspan, and height are presented in **Table 2-4**.

Table 2-4. CRM Parameter Estimates for Aircraft Size

Airspace	Length λ_x (NM)	Wingspan λ_y (NM)	Height λ_z (NM)
Miami Oceanic/San Juan	0.0220 *(134 ft)*	0.0197 *(120 ft)*	0.0065 *(40 ft)*
New York West	0.0261 *(159 ft)*	0.0238 *(144 ft)*	0.0074 *(45 ft)*

2.2.22 *Same-Direction, Opposite-Direction, and Crossing-Route Vertical Passing Frequencies*

2.2.23 The traffic data are used to estimate the vertical occupancy values for the airspace. Table 2-5 shows the same and opposite direction vertical occupancy estimates for the Miami Oceanic/San Juan and New York West airspace in calendar year 2021. As expected, the data show an increase in the vertical occupancy values in 2021 compared to 2020

Table 2-5. Same and opposite direction vertical occupancy estimates

Airspace	Same Direction Vertical Occupancy Value	Opposite Direction Vertical Occupancy Value
Miami Oceanic and San Juan	0.0372	0.0930
New York West	0.0303	0.1184

2.2.24 Crossing-route vertical occupancy is estimated by the number of vertically proximate aircraft pairs on routes that cross at a specific angle, θ. Both mathematical considerations and experience in previous safety assessments have established that the vertical occupancy estimated for pairs of aircraft at intersections of routes is generally less by an order of magnitude than that for pairs of aircraft on the same route at adjacent flight levels. Thus, it is expected that the collision risk estimate for crossing routes will be below the risk for same-route operations at adjacent flight levels. The number of crossing-route aircraft pairs observed in the December 2021 traffic sample from Miami Oceanic and San Juan airspace was 8,130, this is an observed 64% increase from the value observed in 2020. This value, prorated from the 31-sample days for the calendar year 2021, is 95,724 aircraft pairs annually.

2.2.25 *Probability of Vertical Overlap Attributable to Technical Height-Keeping Performance and Reported LHDs.*

2.2.26 RVSM technical risk is considered to arise from the effects of turbulence, loss of altitude hold and crew response to airborne collision avoidance system alerts as well as from errors in aircraft altimetry and altitude-keeping system performance. Hence, estimation of the probability of vertical overlap must account for contributions to vertical error arising from all of these sources.

2.2.27 Estimates of aircraft Altimetry System Error (ASE) and Assigned Altitude Deviation (AAD) are obtained from aircraft height monitoring processes developed by NAARMO. These processes require several data sets, including meteorological and aircraft geometric height data. Aircraft geometric data is obtained from either the U.S. Aircraft Geometric Height Monitoring Element (AGHME), ADS-B data, or the GPS Monitoring Unit (GMU) system. Control of aircraft ASE is one of the principal objectives of the State RVSM approval process, which must be held by operators in airspace where the RVSM is applied.

2.2.28 The NAARMO estimate for the probability of vertical overlap for aircraft pairs operating on adjacent flight levels, Pz(1000), used in the estimate of vertical technical risk is 1.93 × 10-9. The NAARMO estimate for the probability of vertical overlap for aircraft pairs operating on the same flight level, Pz(0),used in the estimation of vertical operational risk is 0.42.

2.2.29 *Time spent at Unexpected/Incorrect FL*

2.2.30 The proportion of flying time spent at incorrect levels, Pi, is determined as the ratio of the amount of time spent at incorrect levels to the total amount of flying time in the airspace during the period when the wrong-flight-level events occurred. The risk-bearing LHDs for calendar year 2021 contain 61 minutes of flying time spent at unexpected flight level.

2.2.31 Table 2-3, provided earlier in this paper, gives the duration at unexpected/incorrect flight level for both areas. The proportion of flying time spent at unexpected flight level is estimated for each area using the values in the table and dividing by the estimated flying hours for each area. The estimated annual flying hours for New York West airspace obtained from the ATOP DR&A data are 298,471 hours. The estimated annual flying hours for Miami Oceanic and San Juan airspace obtained from the combined TFMS data are 319,965 flying hours. The ratios of time spent at unexpected flight level are 3.0 × 10-6 and 4.7 × 10-7 for New York West and Miami Oceanic/San Juan airspace, respectively.

2.2.32 *Collision Risk Model Parameters*

2.2.33 The individual parameters of the models, their definitions, estimates, and sources are given in Table 2-6.

Table 2-6. Vertical Collision Risk Model Parameter Estimates - 2021

Term	Definition	Estimate	Source
$P_z(S_z)$	Probability that two aircraft nominally separated by the vertical separation minimum *Sz* are in vertical overlap.	1.93×10^{-9}	Value used in the US CONUS vertical risk estimate
$P_z(0)$	Probability that two aircraft operating on the same flight level are in vertical overlap	0.42	Value used in the vertical risk estimates for Pacific airspace
$P_y(0)$	Probability that two aircraft on the same track are in lateral overlap.	0.1	Value used in the vertical risk estimates for Pacific airspace
λx	Average aircraft length.	0.0220 NM and 0.0261 NM	Estimated from Miami Oceanic/San Juan and New York West traffic data
λy	Average aircraft wingspan.	0.0197 NM and 0.0238 NM	Estimated from Miami Oceanic/San Juan and New York West traffic data
λz	Average aircraft height with undercarriage retracted.	0.0065 NM and 0.0074 NM	Estimated from Miami Oceanic/San Juan and New York West traffic data
Ez(same)	Same-direction vertical occupancy for a pair of aircraft at adjacent flight levels on same route.	0.0372 and 0.0302	Estimated from Miami Oceanic/San Juan and New York West traffic data
Ez(opp)	Opposite-direction vertical occupancy for a pair of aircraft at adjacent flight levels on same route.	0.0930 and 0.1184	Estimated from Miami Oceanic/San Juan and New York West traffic data
$\overline{\lvert \Delta V \rvert}$	Average absolute relative along-track speed between aircraft on same-direction routes.	13 knots	Value used in the North Atlantic, Pacific, and US Domestic airspace vertical risk estimates

Term	Definition	Estimate	Source
$\overline{\lvert V \rvert}$	Average absolute aircraft ground speed.	480 knots	Value used in the North Atlantic, Pacific, and US Domestic airspace vertical risk estimates
$\overline{\lvert \dot{y} \rvert}$	Average absolute relative cross-track speed for an aircraft pair nominally on the same route.	5 knots	Value used in the North Atlantic, Pacific, and US Domestic airspace vertical risk estimates
$\overline{\lvert \dot{z} \rvert}$	Average absolute relative vertical speed of an aircraft pair that have lost all vertical separation	1.5 knots	Value used in the North Atlantic, Pacific, and US Domestic airspace vertical risk estimates
F(NY)	Estimated flying hours within New York West FIR	298,471	Estimated from FAA ATOP DR&A for New York West airspace
F(MS)	Estimated flying hours within Miami Oceanic and San Juan FIRs	319,965	Estimated from TFMS data for Miami Oceanic and San Juan airspace

2.2.34 Results and Conclusions

2.2.35 The risk-bearing LHDs are separated based on the location of the event. The risk-bearing LHDs within New York West airspace are applied to the estimated flying hours and vertical occupancy values for New York West airspace. The same method is applied to the data for Miami Oceanic and San Juan airspace. Table 2-7 provides the weighted 2021 estimates of technical and operational vertical risk for Miami Oceanic, New York West and San Juan airspace. The last row in Table 2-7 contains the weighted sum of the risk from the two areas.

Table 2-7. 2021 Vertical Risk Estimates for Miami Oceanic, New York West and San Juan Airspace
$\{\times 10^{-9}$ fatal accidents per flight hour (FAPFH)$\}$

Airspace	Technical	Operational	Overall
New York West	0.04	9.76	9.80
Miami Oceanic and San Juan	0.04	4.52	4.56
Total	**0.08**	**14.28**	**14.36**

2.2.36 The estimated technical risk in the RVSM airspace is 0.08 × 10-9 fatal accidents per flight hour (fapfh). This estimate is significantly below 2.5 × 10-9 FAPFH, which is the portion of the TLS set as the safety goal for technical height-keeping performance.

2.2.37 The operational vertical risk estimate for RVSM airspace 14.28 × 10-9 FAPFH. The sum of this value and the technical risk estimate for airspace is 14.36 × 10-9 FAPFH, which is larger than the overall safety goal of 5.0 × 10-9 FAPFH.

2.2.38 The estimated vertical risk estimate for 2021, shown in Table 2-7, is an increase from that estimated for calendar year 2020 but is comparable to the risk estimates from the pre-COVID period (e.g. 2017 – 2019). The increase in the vertical risk estimate is directly related to the increase in the time spent at unexpected flight levels as shown in Figure 2-4. For comparison, Table 2-8 and Figure 2-7 provide the vertical risk estimates for calendar years 2017 through 2021.

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Table 2-8. Vertical Risk Estimates for Miami Oceanic, New York West and San Juan Airspace {× 10^{-9} fatal accidents per flight hour (FAPFH)}

Calendar Year	Technical Risk	Operational Risk	Overall Vertical Risk	TLS
2017	0.05	87.44	87.50	5
2018	0.07	48.04	48.11	5
2019	0.07	20.67	20.75	5
2020	0.07	5.61	5.68	5
2021	0.08	14.28	14.36	5

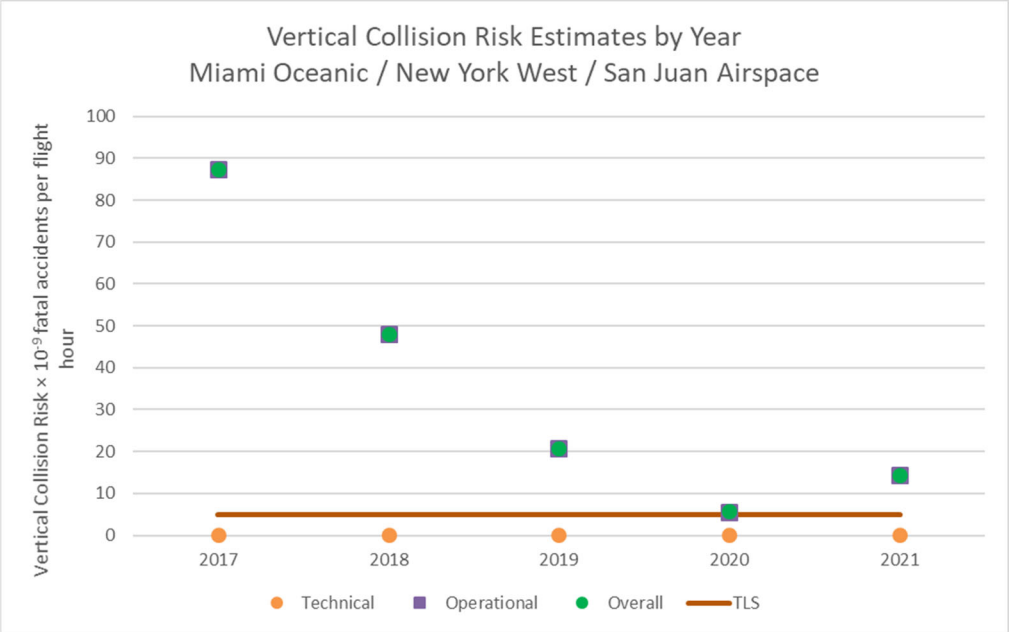

Figure 2-7. Vertical Risk Estimates for Miami Oceanic, New York West and San Juan Airspace {× 10^{-9} fatal accidents per flight hour (FAPFH)}

3. Action Items:

3.1 The GTE is invited to:

a) Note and discuss the information provided.

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